



Detecting Exoplanets with the New Worlds Observer: The Problem of Exozodiacal Dust

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ABSTRACT

Dust coming from asteroids and comets will strongly affect direct imaging and characterization of terrestrial planets in the Habitable Zones of nearby stars. Such dust in the Solar System is called the zodiacal dust (or “zodi” for short). Higher levels of similar dust are seen around many nearby stars, confined in disks called debris disks (see Figure 1). Future high-contrast images of an Earth-like exoplanet will very likely be background-limited by light scattered of both the local Solar System zodi and the circumstellar dust in the extrasolar system (the exozodiacal dust). Clumps in the exozodiacal dust, which are expected in planet-hosting systems, may also be a source of confusion.

Here we discuss the problems associated with imaging Earth-like planets in the presence of unknown levels of exozodiacal dust. Basic formulae for the exoplanet observation times as functions of star, exoplanet, zodi, exozodi, and telescope parameters are given and applied to the New Worlds Observer (NWO) mission. We find that NWO can accomplish its science goals even if exozodiacal dust levels are typically much higher than the Solar System zodi level. Finally, we highlight a few additional complications relating to exozodiacal dust.

1. DEBRIS DISKS

- Optically thin, gas-poor dusty disks around main sequence stars, w/ ages from ~ 10 Myr to a few Gyr
- Material comes from collisions between and evaporation of extrasolar asteroids and comets
- Amount of dust typically quantified using the fractional infrared luminosity, L_{IR}/L_{\star} (the light absorbed by the circumstellar dust and re-emitted at IR wavelengths relative to the stellar luminosity)
- Zodiacal dust interior to Solar System asteroid belt has $L_{IR}/L_{\star} = 10^{-7}$. It has varied between 0.5 – 3.3 times today’s amount over last ~ 80 Myr (Kuchner & Farley 2008).
- L_{IR}/L_{\star} often given in units of “zodis”. One zodi of dust corresponds to a disk with $L_{IR}/L_{\star} = 10^{-7}$; it is not a unit of dust mass or surface brightness.

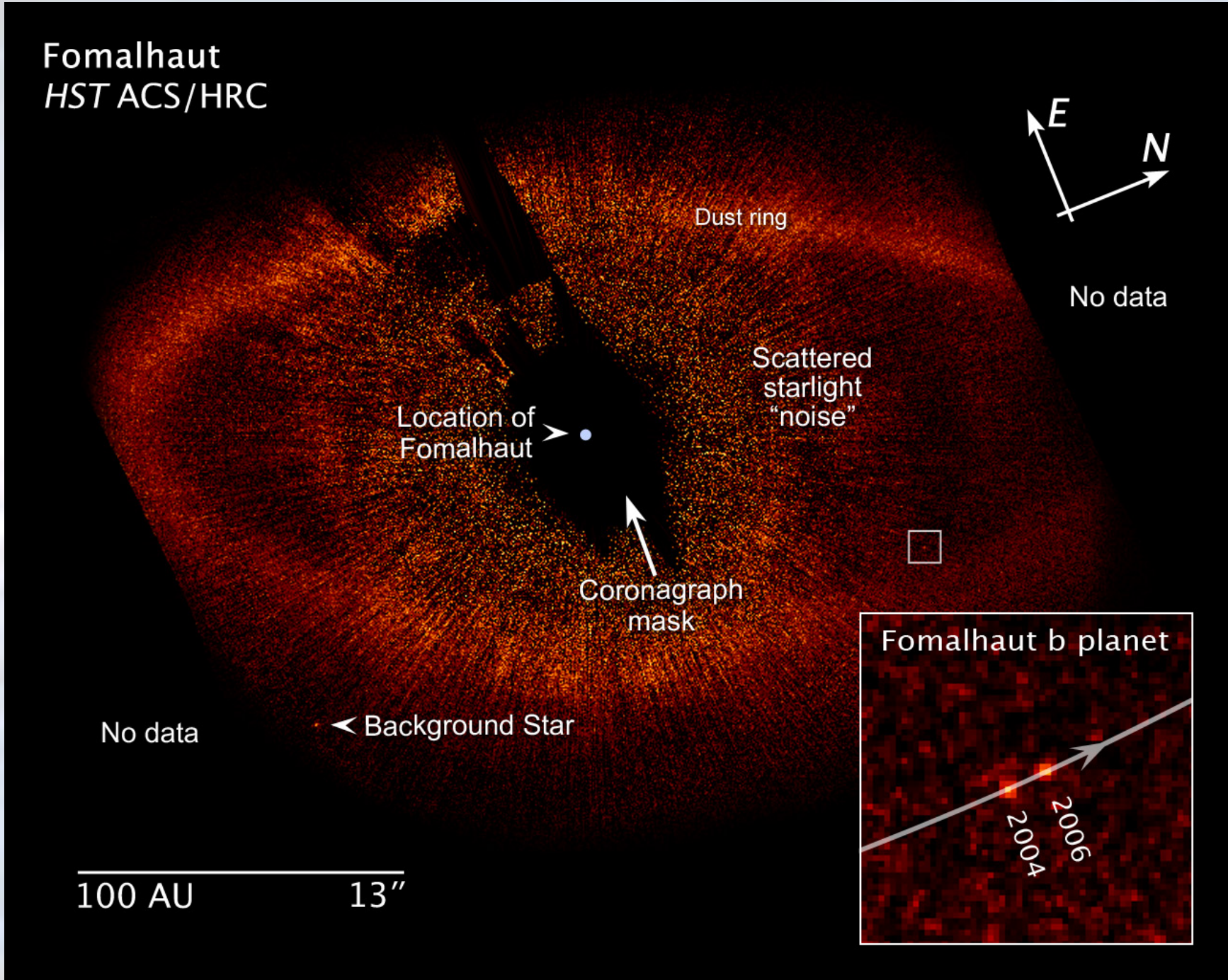


Figure 1: The Fomalhaut debris disk, with a potential exoplanet detected by direct imaging (Kalas et al. 2008). This optical wavelength coronagraphic image was taken with the HST ACS camera. Image credit: NASA, ESA, and Z. Levay (STScI)

3. NWO PERFORMANCE

- How many Earths can NWO characterize over its lifetime?
- Expect to do spectroscopy on $\eta_{Hab \text{ Earth}}$ of the targets. Minimum imaging time = 1 day.
- Total mission = 5 years, Exoplanet observations = 1 year.
- Results for $\eta_{Hab \text{ Earth}} = 0.25$ plotted in Figure 3. Results for various values of $\eta_{Hab \text{ Earth}}$ shown in Table 1.
- Most stars chosen are G and K stars; no M stars.

NWO can achieve its science goals over large ranges of exozodi brightness and $\eta_{Hab \text{ Earth}}$

4. FUTURE WORK

- Study effect of confusion due to clumps in the exozodi dust. What is best way to distinguish between dust and planets? Maybe multi-color imaging, then low resolution spectroscopy?
- Solar System zodi scatters red. Likely that exozodi will have diversity of colors (red, grey, blue). How to deal with colored background light in planet spectra?

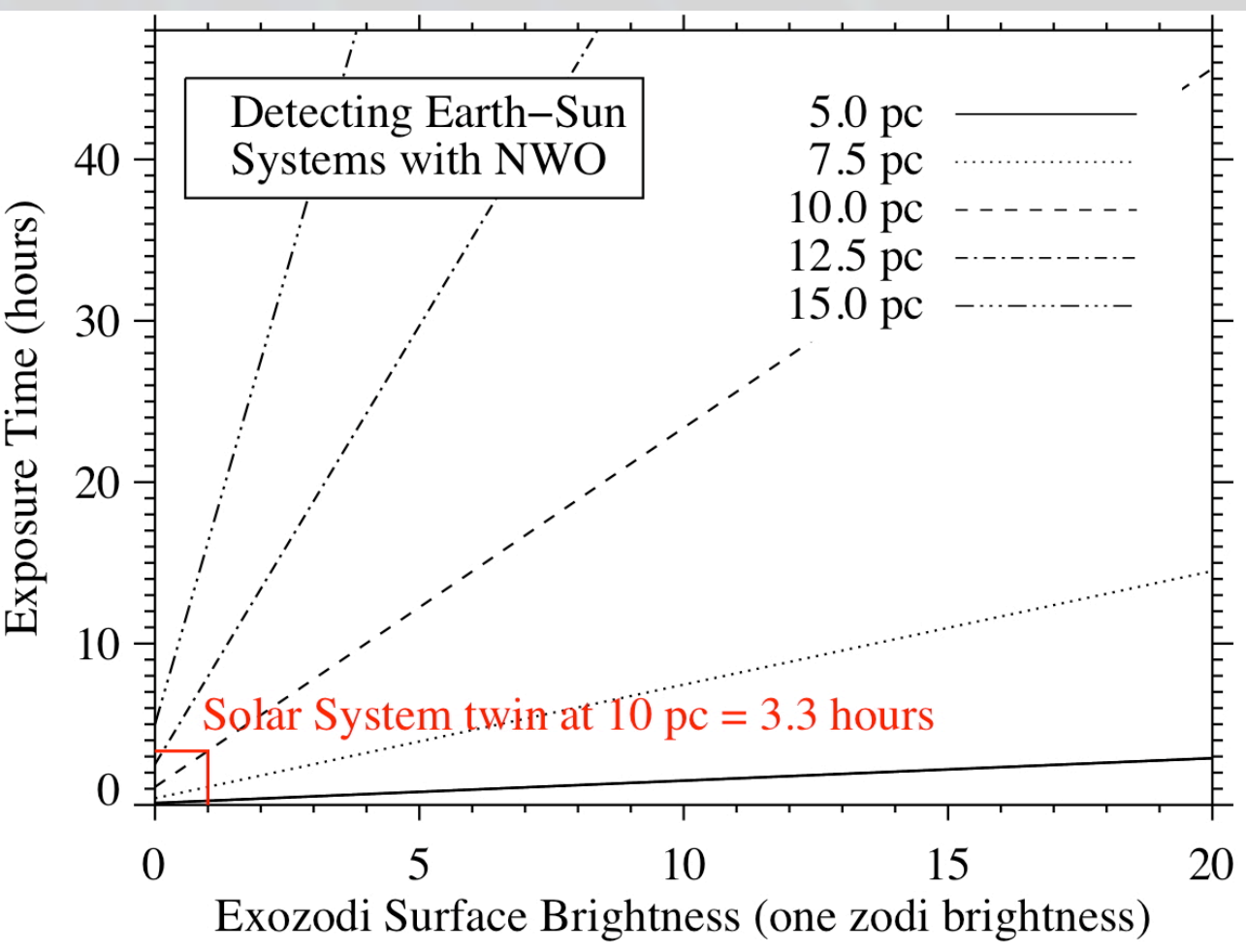


Figure 2: Time to image an Earth-like planet at S/N = 10 in a “Solar System twin” (1 zodi of exozodiacal dust) at various distances. The curves were calculated using the equation at left. See Turnbull et al. (2009) for details.

2. THE PROBLEM

- Light scattered off local zodi and exozodi will mix into planet images and spectra.
- Even for very low exozodi levels, zodi/exozodi background will be dominant source of noise for most stars.

Formula for planet imaging exposure time

$$t = \frac{2 n_x \lambda^2}{\pi F_0 \Delta \lambda D^4 T} \left(\frac{S}{N} \right)^2 10^{0.8(M_p + 5 \log d - 5)} \left[\left(\frac{206265''}{1 \text{ rad}} \right)^2 (10^{-0.4z} + \mu 10^{-0.4x}) + \zeta 10^{-0.4m_*} \left(\frac{\pi D^2}{4 \lambda^2} \right) \right]$$

where n_x = number of pixels in a critically sampled diffraction limited image, λ = central wavelength of the imaging bandpass, F_0 = specific flux for zero mag in the bandpass, $\Delta \lambda$ = bandpass width, D = telescope diameter, T = total facility throughput, S/N = signal-to-noise, M_p = absolute magnitude of the planet in the image bandpass, d = distance to system in pc, z = surface brightness of the zodiacal dust in mag arcsec⁻², μ = exozodi surface brightness in units of the surface brightness of one zodi of exozodiacal dust, x = surface brightness of one zodi of exozodiacal dust in mag arcsec⁻², ζ = contrast level in the detection zone relative to the theoretical peak of the stellar image, m_* = apparent stellar magnitude, and $(\pi D^2/4\lambda)$ = theoretical peak brightness of the stellar PSF.

Formula for estimated planet spectroscopy exposure time

$$t_{\text{spec}} \approx \left(\frac{\Delta \lambda_{\text{image}}}{\Delta \lambda_{\text{spec}}} \right) \times t_{\text{image}} \approx \left(\frac{\Delta \lambda_{\text{image}}}{\lambda/R} \right) \times t_{\text{image}} \approx \left(\frac{200 \text{ nm}}{600 \text{ nm}/100} \right) \times t_{\text{image}} \approx 33.3 \times t_{\text{image}}$$

where $\Delta \lambda_{\text{image}}$ = imaging bandpass width, $\Delta \lambda_{\text{spec}}$ = width of one spectral resolution element, t_{image} = imaging exposure time for some S/N, λ = central wavelength of the spectrum, and R = spectral resolution.

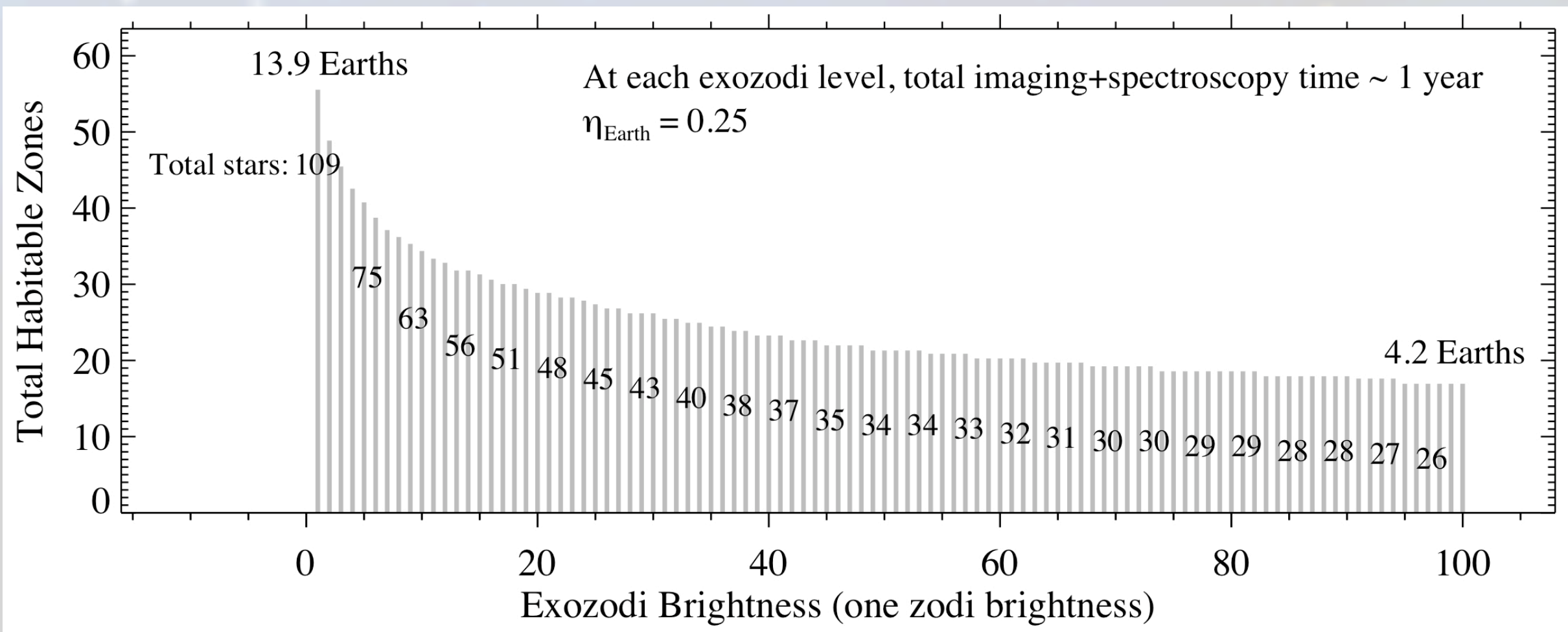


Figure 3: Total HZs searched vs. exozodi brightness, w/ $\eta_{Hab \text{ Earth}} = 0.25$. The y-axis is the cumulative completeness for all the stars observed assuming each one has the exozodi brightness given on the x-axis. For each star, we calculated 1) the exposure times for exozodi brightnesses from $\mu = 1$ to $\mu = 100$ and 2) weighting factors (completenesses / exposure times). At each exozodi level, the stars with weights greater than some limit were chosen for observation. We iterated to find the weight limits that gave total program time ~1 year at every exozodi level. The total program time was calculated assuming that for $\eta_{Hab \text{ Earth}} \times 100 = 25\%$ of the targets, we obtain a spectrum with $S/N \geq 10$ and $R = 100$ in addition to the imaging observation. The numbers appearing on some of the grey bars are the total numbers of stars observed. The total number of Earths characterized is $\eta_{Hab \text{ Earth}} \times$ the total HZs searched at each exozodi level. For $\eta_{Hab \text{ Earth}} = 0.25$, we can characterize 13.9 Earths if all stars have $\mu = 1$ and 4.2 Earths if all stars have $\mu = 100$.

Table 1			
$\eta_{Hab \text{ Earth}}$	Stars Observed ($\mu = 1, \mu = 100$)	Total HZs Searched ($\mu = 1, \mu = 100$)	Total Earths Characterized ($\mu = 1, \mu = 100$)
0.10	144, 35	67.3, 22.0	6.7, 2.2
0.25	109, 26	55.5, 16.9	13.9, 4.2
0.50	88, 21	46.8, 14.3	23.4, 7.2
1.00	71, 12	39.8, 12.0	39.8, 12.0